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PROLIFERATION RESISTANCE CRITERIA FOR FISSILE MATERIAL DISPOSITION ISSUES

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ABSTRACT

The 1994 National Academy of Sciences study "Management and Disposition of Excess Weapons Plutonium" defined options for reducing the national and international proliferation risks of materials declared excess to the nuclear weapons program. This paper proposes criteria for assessing the proliferation resistance of these options as well defining the "Standards" from the report. The criteria are general, encompassing all stages of the disposition process from storage through intermediate processing to final disposition including the facilities, processing technologies and materials, the level of safeguards for these materials, and the national/subnational threat to the materials.

I. INTRODUCTION

This paper discusses criteria for assessing the proliferation resistance of the materials, technologies, alternatives and facilities composing the options for disposition of surplus weapon fissile materials. As stated by the 1994 National Academy of Sciences (NAS) study "Management and Disposition of Excess Weapons Plutonium," "the primary goal in choosing options for the management and disposition of excess weapons fissile materials should be to minimize the risks to national and international security." The NAS divides this goal into three objectives: reducing the risk of proliferation by unauthorized parties, reducing the risk of reintroduction of the materials into the arsenals from which they came, and strengthening national and international control of fissile materials. The NAS study also recognized the importance of considering the proliferation resistance inherent in all phases of disposition from the current state of the materials through processing to final disposal. In addition, the study considered the implications of US excess weapons materials disposition as a model for the ultimate disposition of fissile materials, both in weapons and in commercial fuel cycles worldwide, recognizing that each country will view disposition options in the context of their specific fuel cycle plans.

Our paper endorses this broad view of proliferation resistance, proposing criteria, for evaluating the proliferation resistance of plutonium disposition options, that 1) encompass all stages of disposition from storage through intermediate processing to final disposition, 2) consider the varying threat /safeguards environment in each country, and 3) accommodate the varied nuclear fuel cycle plans of each country. The paper also evaluates the Stored Weapons Standard (SWS), the Spent Fuel Standard (SFS), and Beyond the Spent Fuel Standard (BSFS) from the NAS study.

II. COMPONENTS OF PROLIFERATION RESISTANCE

The proliferation resistance of a disposition option is determined by the material form, the physical access afforded by the technology/facility that processes or stores the material, the level of safeguards and security that isapplied and the national/subnational threat to the material. All of these factors affect the resources and technical complexity for acquiring, transporting, and processing the material for use in a nuclear explosive. Because any disposition option is a time-variant path from the current state of the material to the final disposition state, the total proliferation resistance is a function of the proliferation resistance at each stage. The spent fuel standard suggested by the NAS focuses only on the form of the surplus fissile materials and only on its final state. It does not encompass other components of proliferation resistance nor the steps of disposition leading up to the final disposal.

A. Material Form

The form of the material in terms of its radiological, chemical, and physical characteristics affects the difficulty of acquiring the material and processing it for use in a nuclear explosive. Materials, such as spent fuel, that are highly radioactive cannot be handled directly, requiring instead shielding and remotely operated equipment to avoid lethal radiation doses. This increases the technical complexity of both acquiring and processing these materials.

The technical complexity and time required to process the material in to a form usable in a nuclear explosive depend on the chemical form. Materials such as plutonium metals, oxides, or carbides require limited or no processing. Low concentrations of plutonium in spent fuel or other waste forms require more complex processing equipment and longer times to separate fission products and other matrix materials to obtain plutonium in sufficient quantity for a nuclear explosive.

Physical form, especially size and weight, affects proliferation resistance in terms of the difficulty of moving the material to a location where it can be processed. For example, plutonium in the form of containers of oxide powder is readily transportable, whereas plutonium in a spent fuel assembly from a light-water reactor requires special equipment for lifting, handling, and transport.

B. Physical Access

Ease of access to material depends on the number and kinds of barriers surrounding the material locations and the extent to which penetrations in these barriers are sealed or controlled. Clearly, those facilities with limited or no access to material by workers provide greater barriers to the material. For example, material temporarily stored in a receiving area is more accessible than material in long-term storage in a vault or in a geologic repository. In processing facilities, more barriers are provided by modern automated facilities where control is remote and personnel access is not required than by older facilities with hands-on access through glove boxes. Although such barriers increase proliferation resistance for the contained materials, the remoteness of the materials complicates the materials accounting aspects of safeguards.

C. Safeguards and Security

The application of domestic and international safeguards will vary from country to country. Domestic safeguards generally consist of materials control and accounting and physical protection measures with the goal of detecting and interrupting unauthorized attempts to access nuclear materials. International safeguards consist of verifying a state's system of accounting using materials accounting methods complemented by containment and surveillance. The international safeguards regime does not have a role of protecting materials; instead, it confirms the correctness of the states' declarations.

The DOE, the Nuclear Regulatory Commission (NRC), and the International Atomic Energy Agency (IAEA) have developed criteria for evaluating the relative attractiveness of nuclear materials for use in weapons. These criteria determine a graded safeguards approach wherein materials that are most readily used for nuclear explosives are assigned increased safeguards. The criteria are generally related to the amount of the material required for a single weapon (significant quantity), the time to process the material to a weapons-usable form, and the technical difficulty of processing to this form.

1. DOE. The DOE assigns attractiveness levels to the various forms of plutonium according to the amount of processing required to obtain weapon-usable material. These levels in order of decreasing attractiveness are 1) assembled weapons and test devices; 2) directly convertible materials such as pits, buttons, and ingots; 3) high-grade materials such as oxides, carbides, and nitrates; 4) low-grade materials such as process residues; and 5) highly irradiated forms. A graded safeguards approach is applied with the higher attractiveness levels and larger material amounts receiving more stringent materials accounting and physical protection. The highest level of protection is applied to attractiveness level 1 materials in amounts of 2 kg or more. The lowest level of protection is applied to irradiated forms such as spent fuel.

2. NRC. The NRC also applies a graded approach to materials accounting and physical protection with more stringent measures applied to increasing amounts of plutonium. Amounts of plutonium in excess of 2 kg receive the strongest protection measures. However, for plutonium in self-protecting material, defined as radioactive material with a total external radiation dose rate in excess of 100 rems per hour at 3 ft, the materials accounting and physical protection requirements are reduced.

3. IAEA. The IAEA defines a significant quantity of plutonium as 8 kg and prescribes materials accounting and containment/surveillance measures according to the attractiveness of the material for use in a weapon. The attractiveness criteria consider the difficulty of processing the material and the time to process. The safeguards must meet timeliness and detection probability goals based on the material form. The loss of a significant quantity of plutonium in separated form must be detected with high probability within 1 month. The loss of a significant quantity of plutonium in spent fuel must be detected with high probability within 3 months.

D. Conflicts Between the Proliferation Resistance Components

Material form, physical access, and safeguards are interrelated, with variations in one component affecting the proliferation resistance of the others. Indeed, these components of proliferation resistance may sometimes be in conflict such that increases in the proliferation resistance of one component decrease the effectiveness or increase the cost of another component. For example, materials in item form are more readily safeguarded than materials in bulk form where measurement uncertainties complicate precise accounting for the material; restrictions on physical access lower the threat of theft while limiting the ability to confirm continued material presence; and material forms that are radioactive improve the self-protection of the materials while complicating the problem of measuring the material. This suggests that selection of a disposition option should include an examination of the tradeoffs between all of the proliferation risk components.

III. PROLIFERATION RESISTANCE OF DISPOSITION PATH

The level of proliferation resistance will vary as the material moves from its initial state through processing (if needed) to final disposal. In some instances, material might remain in storage for an extended period with no change in proliferation resistance. But in other instances the material could be removed from storage, transported, and processed in a bulk facility, where safeguards are technically more difficult to apply, with a consequent reduction in resistance. The NAS study identified the need for proliferation resistance at three stages in the disposition process.

> Storage. "The security offered by indefinite storage against the risks of breakout and theft is entirely dependent on the durability of the political arrangements."
>
> Handling. "Although options [for final disposition] decrease the long-term accessibility of the material for weapons use, they could increase the short-term risks of theft or diversion because of the required processing and transport steps."
>
> Recovery. (The spent fuel standard) "We believe that the options for long-term disposition of weapons plutonium should ... make this plutonium as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in commercial reactors."

IV. PROLIFERATION RESISTANCE AND THREAT

The level of the proliferation threat depends on the country dependent and can include 1) insiders working in a facility and employing either violence or stealth, 2) outsiders such as criminals or terrorists, and 3) a national threat posed by a nation's decision to employ plutonium in a weapons program. The technical strength of the criminal or terrorist threat in terms of ability to access and process these materials or the political decision of a nation to initiate a weapons program strongly affects the proliferation resistance of the disposition options.

The following summary of threats and safeguards in selected states indicates the diversity of proliferation environments to be addressed by any program for global disposition of fissile materials.

A. Nonproliferation Treaty (NPT) Countries with Full-Scope Safeguards Agreements (INFCIRC 153)

These non-nuclear weapons states, including Canada, Germany, Belgium, Italy, Sweden, and Japan, have all signed the NPT and maintain States Systems of Accounting and Control (SSAC) that are consistent with IAEA standards (INFCIRC 153) and are verified by the IAEA. In countries that are members of the Commission of European Communities, the SSAC is maintained by the EURATOM safeguards agency, which conducts independent inspections as well as joint inspections with the IAEA. In addition, all of these NPT countries apply physical protection measures consistent with the IAEA guidance (INFCIRC 225) that sets international standards for such measures. Countries in this category could be considered to have a low proliferation threat environment and a high level of safeguards.

B. France, UK, and US

These nuclear weapons states have signed the NPT and have submitted a list of commercial nuclear facilities that the IAEA can select for full or limited inspections under Voluntary Agreements with these states. These states maintain an SSAC and their physical protection conforms to INFCIRC 225 standards. In addition, their weapon materials are also under just as strong safeguards and security measures as are the materials in their commercial fuel cycles. These countries have low proliferation threat environments and a high level of safeguards.

C. States of the Former Soviet Union

Russia has signed the NPT and, as a nuclear weapons state, accepts limited inspections of some nonweapons facilities under a Voluntary Agreement with the IAEA. Although Russian accounting for nuclear materials has traditionally been limited, physical protection measures were strong. However, there are recent signs that the physical protection system may be eroding. Kazakhstan and Ukraine have similar weaknesses in materials accounting. However, Kazakhstan has signed an agreement with the IAEA to apply full-scope safeguards to all nuclear facilities, and Ukraine is negotiating inspections by the IAEA. Acceptance of IAEA safeguards will require both countries to establish an improved SSAC. The criminal and terrorist threats in these countries have been much higher than in the full-scope NPT countries.

D. States with Limited Inspections by the IAEA (INFCIRC 66)

India, Pakistan, and Israel have not signed the NPT but have limited agreements with the Agency for safeguards on selected materials in their fuel cycles. Thus, all nuclear materials in these countries are not under international safeguards, and the level of safeguards in these countries is significantly less than in the full-scope countries. Argentina and Brazil have formed a regional safeguards system (ABACC) for mutual inspections and are negotiating NPT agreements with the IAEA. The threat of continued proliferation is, of course, high in India, Pakistan, and Israel where all three are suspected to have nuclear weapons production capability with a limited stockpile, whereas in Argentina and Brazil the proliferation trend is reversed.

E. Threshold Nuclear States

Iraq and North Korea, although signatories of the NPT, are clearly states that have had proliferant nuclear activities. Iran is an NPT signatory but is suspected of having a clandestine nuclear weapons program.

V. THE "STORED WEAPONS STANDARD"

The SWS and SFS are the two 'standards" from the NAS report that are fundamental to the Fissile Materials Disposition Project (FMDP). The SWS and the SFS are the two fundamental definitions for fissile material disposition that can be applied to the life cycle stages of fissile material usable in weapons. Unlike most "standards," they are elusive and ever enduring like the work that surrounds the ultimate disposition of weapons-usable fissile material. One can apply these two "standards" to a snapshot of the disposition options in time but generally a standard will not apply throughout the life of the disposed fissile material weapons (See Figure 1). That is why proliferation resistance is at the "heart" of the entire program. One example is "spent fuel." We can apply the SWS throughout the life of the fissile material until it comes out of the reactor, then the SFS applies as well as the SWS until the fissile material meets the preferred criteria and is proliferation resistant. As the radiation barrier decays away in the repository, the SWS safeguards must increase.

In the Los Alamos report, LA-12935-MS, there is full definition of the SWS as identified in the NAS study. These two "standards" can only be considered under the umbrella of proliferation resistance, not separate from it; "Beyond the Spent Fuel Standard," also cannot be considered separately. Figure 2 shows the relationship between the "standards" option and proliferation resistance.

The definition of SWS uses the DOE Orders and the Joint Nuclear Weapons Publications (DOE-DNA, TP 0-1) documents that regulate nuclear materials control and physical protection (and sub-categories thereof) and the knowledge of experts in the methods and technologies for implementing these orders, policies, rules, and regulations. Among the documents used to establish a regulatory basis for the SWS, are the 5600 Series of the DOE Orders. This document hierarchy establishes graded safeguards throughout the life of the material. DOE Orders have successfully defined safeguards and security for fissile material throughout its complex life, from its birth, through fabrication, and on to deployment as a nuclear weapon. At that point DOE-DNA have technical publications (Custody, Accountability, and Control of Nuclear Weapons and Nuclear Material/DOE-DNA, TP 100-4) that regulate the fissile materials. Then, the fissile material will undergo a complex life cycle from the time it comes from a dismantled weapon until its conversion, and then to final disposition. This standard must be sufficiently robust to accommodate these life-cycle changes, now under the umbrella of proliferation resistance, accommodating IAEA full scope safeguards and possibly bilateral and multilateral agreements. We assume that this standard will cover the life of the material from an intact nuclear weapon to its final disposition. We can apply a graded approach to safeguards and security, as defined by the DOE Orders, which is applicable not only to weapons in specialized storage facilities but also to the materials, technologies, and facilities anticipated for the entire disposition process.

VI. THE "SPENT FUEL STANDARD"

The SFS defines proliferation resistance in terms of just the self-protecting attributes of the material (radioactivity, size, and weight) and its need for chemical processing to obtain plutonium. However, this emphasis on

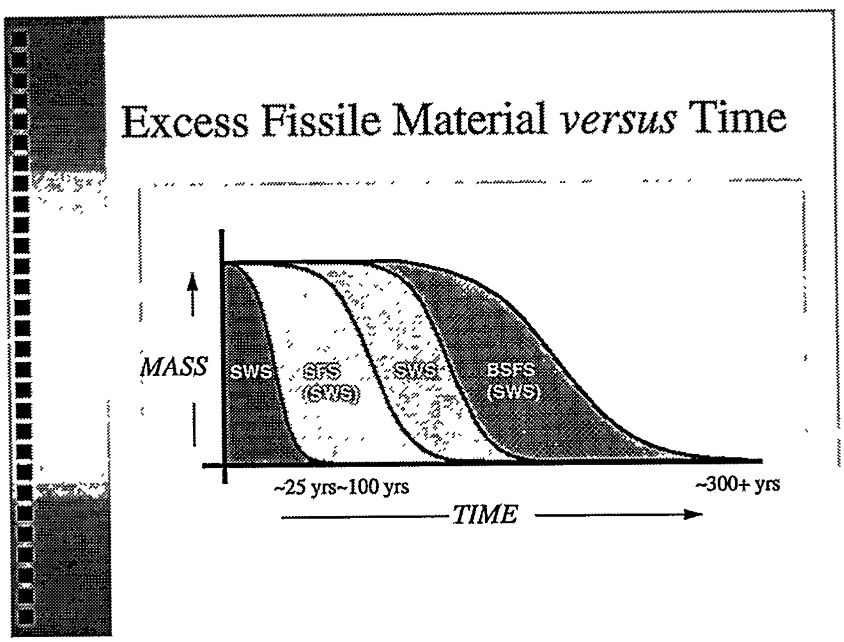

Fig. 1: The relationship between fissile material alternatives, standards, and time.

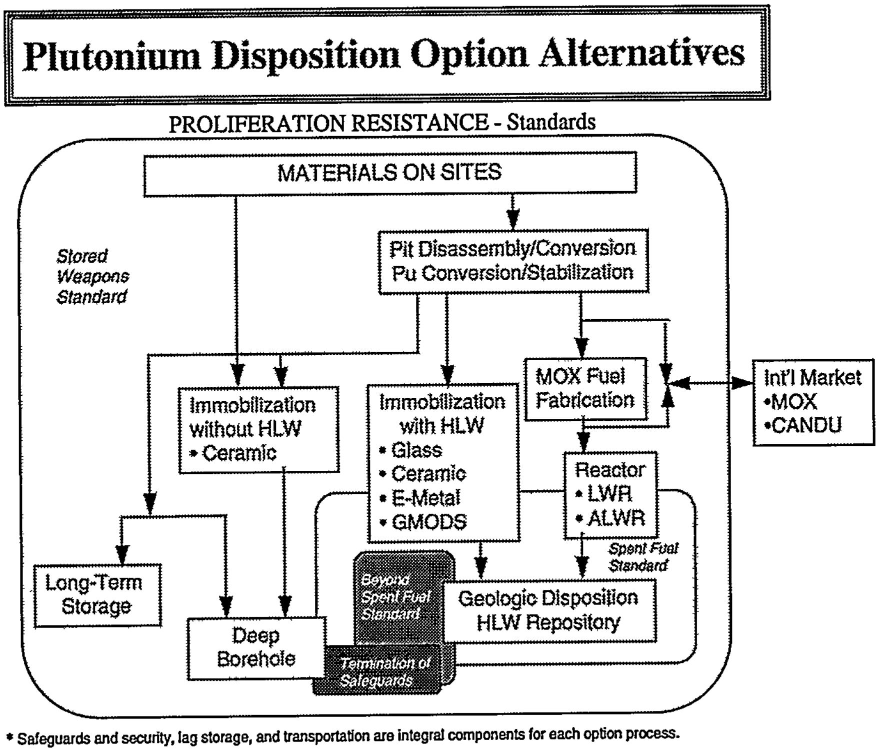

Fig. 2: Proliferation Resistance Criteria from LA-12935-MS. Stored Weapons Standard, Spent Fuel Standard, and Beyond Spent Fuel Standard are shown in relation to the Fissile Material Disposition Options and Alternatives.

material form ignores other aspects of proliferation resistance including 1) the proliferation resistance factors of physical access and safeguards 2) the indigenous threat of unauthorized use of the material for weapons purposes within a State 3) the threat of reintroduction of the materials into a State's nuclear arsenal, and 4) the need to address the proliferation resistance of the complete disposition path.

The focus of the SFS on material attributes neglects the two important factors, physical access and safeguards, that affect proliferation resistance by limiting unauthorized access to the material. Physical access to material is affected by facility or natural barriers such as storage vault walls or burial in a geologic repository. Although the radiation field of a spent fuel assembly contributes to the difficulty of accessing it, the radioactivity decreases with time. Access is further restricted by domestic safeguards and security measures that detect and interdict unauthorized attempts to access material.

As discussed in Section IV, the proliferation resistance of material to unauthorized use is strongly affected by the threat environment in the country where the materials reside. Thus, the value of the material form, physical access barriers, and safeguards in improving proliferation resistance cannot be known until these factors are meas-ured against the threat (criminal, terrorist, or national). Clearly, proliferation resistance of spent fuel in Iraq, Russia, and the US would vary with each country even though the material attributes are similar in each case.

In addition to the proliferation resistance of materials to unauthorized use, the reintroduction of fissile materials into the arsenals of the nuclear weapons States is also a major concern. Declared nuclear weapons States all have operational reprocessing capabilities for extracting plutonium from spent fuel and have performed this process for years. Therefore an SFS does not prevent these States from reintroducing the materials into their weapons stockpiles. At most it may delay such a move. The benefits of such a delay can only be realized if international safeguards are in place to provide detection. Nuclear weapons States could of course simply reprocess spent fuel from civilian reactors, which the Russians have traditionally done for weapons materials and which other nations are doing for plutonium for civilian reactor fuel.

The SFS focuses only on the final disposition state of the material, ignoring the proliferation resistance of the prior storage and processing stages necessary to reach the spent fuel end state. For example, in some countries plutonium could be considered more secure in a storage vault versus an alternative that lowers proliferation resistance by removing plutonium from storage, processing it in a bulk facility where safeguards are technically more difficult, and transporting it to a reactor. The net decrease in proliferation resistance during this process may exceed any added resistance value of the spent fuel form.

Finally, adoption of an SFS neglects the implication that the proliferation resistance criteria adopted for the US plutonium disposition process could serve as a model for global fissile material disposition. Thus, it may not be beneficial for the US to adopt a standard for judging plutonium disposition that cannot encompass the policies of other important holders of plutonium such as France, Japan, Russia, and the UK. Indeed, without reciprocal cooperation from Russia, we have not appreciably reduced the nuclear danger. A more broadly based set of criteria are needed, flexible enough to accommodate a diversity of disposition options, while assuring a global increase in proliferation resistance for plutonium.

VII. BEYOND THE "SPENT FUEL STANDARD"

The focus on the disposition of this material is not just on plutonium from excess weapons, but on all of the world's plutonium stocks. Specifically, this standard will focus on the disposition and elimination of plutonium in spent fuel. Safeguards and security requirements for this standard should use the graded approach as determined for spent fuel in the United States by the NRC and the DOE. Each elimination option for spent fuel will be fully discussed at a later date.

VIII. PROPOSED CRITERIA FOR MEASURING PROLIFERATION RESISTANCE OF PLUTONIUM DISPOSITION OPTIONS

The following criteria are proposed as comprehensive measures of the proliferation resistance of the fissile materials disposition process in an arbitrary threat/safeguards context.

A. Factors Affecting the Technical Difficulty of Acquiring Material

1. Physical Access. The physical location of the material can affect its accessibility to a proliferator. Natural, facility, or process equipment barriers are all factors in determining ease of access. For example, spent fuel in a geologic repository is clearly less accessible than spent fuel in a pond. (Measure: number and types of barriers between threat and material)

2. Safeguards/Physical Protection. The detection and prevention of an access attempt depend on the levels of safeguards and physical protection at the facility. In general, safeguards are more easily applied and more readily verified when materials are in the form of discrete, uniquely identifiable items (such PuO_2 in sealed containers) as opposed to materials in bulk form in a chemical processing facility. (Measure: quality of safeguards, e.g., physical protection consistent with INFCIRC 225, safeguards consistent with DOE Order 5633.3B, verification consistent with IAEA INFCIRC 66 or 153)

3. Self-Protection Aspects of the Material. Characteristics of the material can complicate gaining physical control of a significant quantity of the material. For example, radioactivity of spent fuel increases the technical complexity of acquiring the material. (Measure: rads/h at 1 m, number of items for 1 significant quantity)

4. Physical Form. Characteristics of the material that increase the technical complexity of its transport to a location where it can be processed are the size, weight, and radioactivity of the materials required for a significant quantity. Clearly, a spent fuel assembly is more difficult to transport than a container of separated plutonium. (Measure: size, weight, radioactivity)

B. Factors Affecting the Difficulty of Processing the Material

1. Technical Difficulty of Processing. The technical complexity of recovering a significant quantity of the material through chemical reprocessing and isotopic enrichment, for example, is a measure of the difficulty of processing the material. (Measure: concentration of plutonium, chemical form)

2. Time of Processing. The time to recover a significant quantity will depend on the available technology, the initial form of the material, chemical processes, and the amount of material that must be processed to achieve a significant quantity. Clearly, materials having a low concentration of plutonium will require longer processing times. (Measure: time to process 1 SQ)

3. Financial and Technical Infrastructure. The infrastructure required to support the scientific and engineering knowledge needed for the design and construction of the processing facilities helps determine the difficulty of processing the material. (Measure: cost of processing facility)

The relative importance of these criteria varies with the threat and the proliferation environment. For example, financial and technical infrastructure and physical form are not particularly important if the threat is the reintroduction to a weapons state's stockpile; instead international safeguards, time of processing, and physical access may be the key criteria. On the other hand, financial and technical intrastructure and physical form may be the key criteria for a threshold nuclear state.

IX. SUMMARY

Criteria for evaluating the proliferation resistance of proposed disposition processes for plutonium should be sufficiently comprehensive to include resistance at all stages of the disposition process as well as resistance factors that depend on the threat and safeguards environment in each country. In this paper we proposed general proliferation resistance measures that encompass these factors and evaluated the Stored Weapons Standard, the Spent Fuel Standard, and Beyond the Spent Fuel Standard. We have specifically avoided the concept of a single criterion such as the "spent fuel standard" that addresses only the end stage of the disposition process and does not address sensitivity to the threat or safeguards environment in a country.